Transmission Topology Optimization Software

A Grid-Enhancing Technology Deployable Today Without New Hardware

Pablo A. Ruiz

FERC Workshop on Grid-Enhancing Technologies, Docket No. AD19-19-000
November 6, 2019

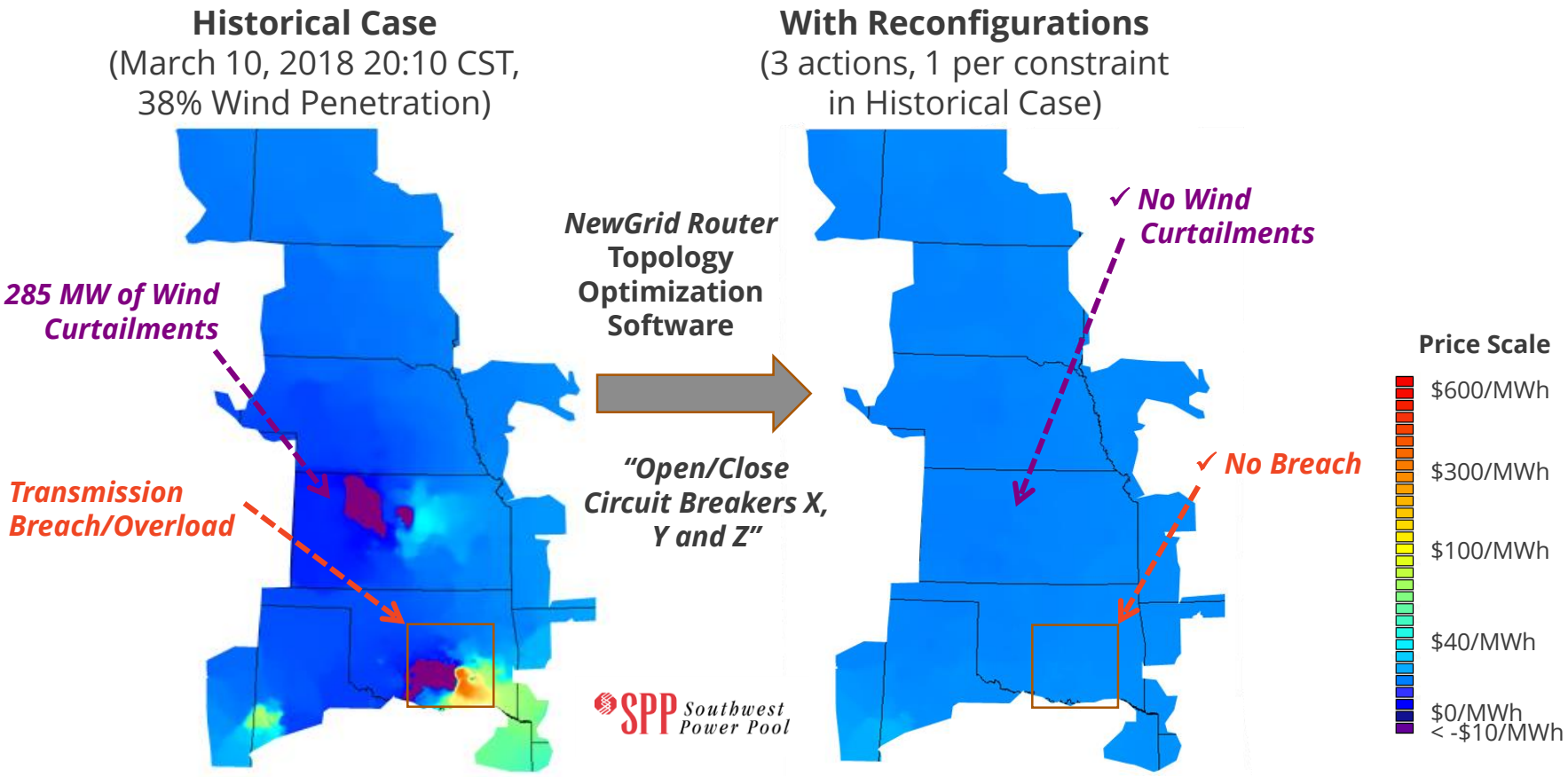
newgrid

Agenda

- Topology Optimization Technology
  - *"Waze for the transmission grid": finds reconfiguration options to route around congested/overloaded facilities*
- Reconfiguration Implementation
  - *Reconfigurations are applied by switching existing circuit breakers (an extremely reliable operation) at a very low cost ($10-100/action)*
- Reconfiguration Practice
  - *Traditionally reconfigurations are found based on staff experience and used on a limited, ad hoc basis*
- Reliability Criteria
  - *Reconfigurations meet operator-specified N-1 and other reliability criteria*
- Applications and Impacts
  - *Reconfigurations adapt the grid to best address system conditions, providing significant resilience, reliability and economic benefits*
- Deployment
  - *The WATT incentive proposal would help overcome barriers to deployment, as would clarifications from FERC on relative priorities*

Topology Optimization

Topology optimization software technology (developed with DOE ARPA-E support) automatically finds reconfigurations to route flow around congested elements ("Waze for the transmission grid")



Case Study: Overload and Congestion Relief

Found single-action reconfiguration options that fully relieve overloads and congestion on a critical, frequent SPP constraint under multiple conditions

Price Scale

$600/MWh

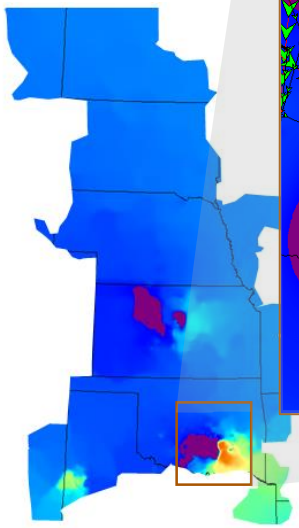
$300/MWh

$100/MWh

$40/MWh

$0/MWh

< -$10/MWh

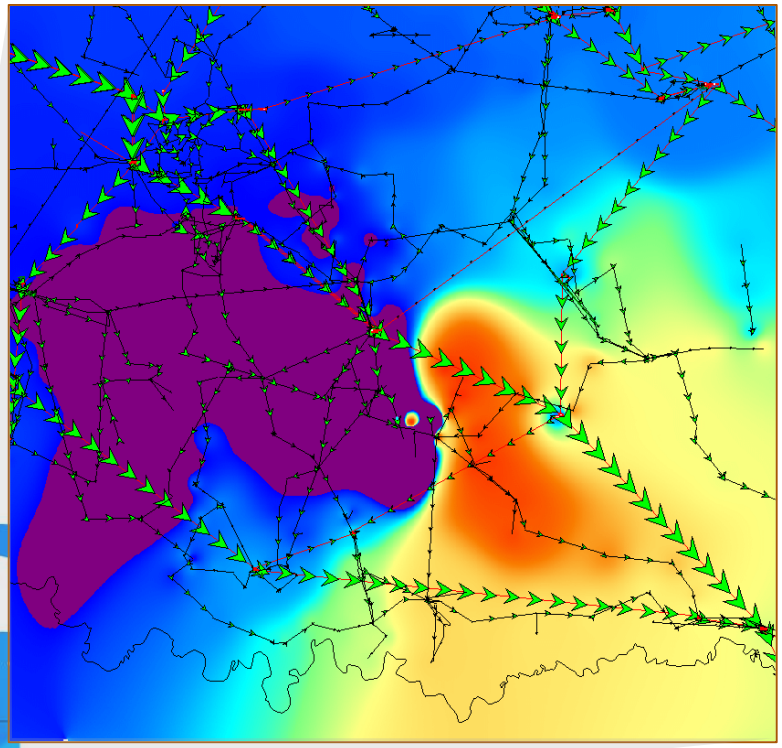


Historical Case

Breached constraint

Shadow price: **$984/MWh**

Third most congested constraint in SPP in 2018*



SPP Real Time Market, March 10, 2018, 20:10 CST

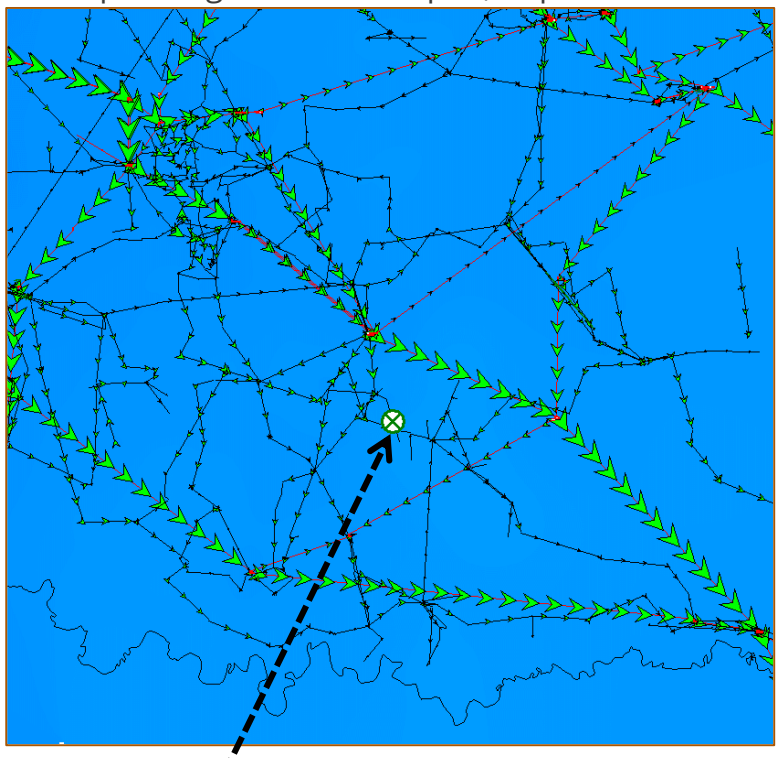
* SPP State of the Market 2018, Figure 5-5

With Reconfiguration

No breach, full congestion relief

Over 25% flow reduction

Operating Guide developed, implemented

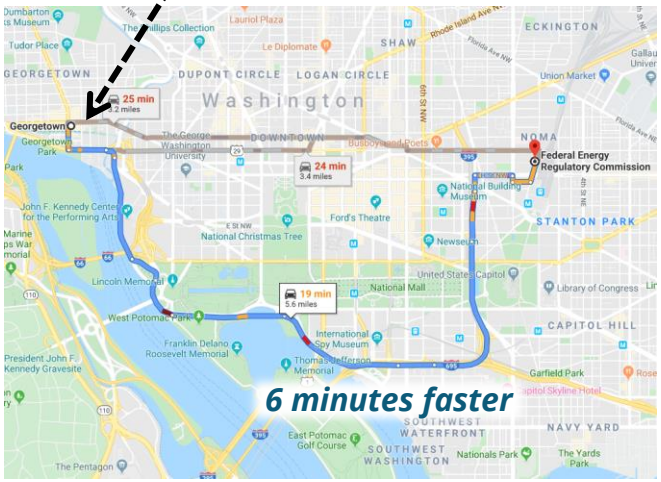


Open one 138 kV line upstream of congestion, which routes flow to 345 kV system

Reconfiguration Implementation

Topology optimization is analogous to Waze: "Arrive to destination reliably, with minimum delay even when there are events on the road."

- Reconfigurations are implemented by switching circuit breakers open or close
  - Analogous to temporarily diverting traffic away from congested roads to make traffic smoother
- Feasibility assessment:
  - *Circuit breakers are capable of high duty cycles & extremely reliable*
    - Two designs: 2k or 10k switching cycles per maintenance overhaul
    - Some breakers are switched very frequently today, e.g., those connecting generating units with daily start and stop
    - Failure occurs less than once in 20,000 switching cycles*
  - *Switching infrastructure is already in place:*
    - Most breakers are controlled remotely over SCADA by the TO
    - Phone call between TO and RTO to coordinate operations
  - *Low cost*: usually $10-$100 per switching cycle**



* For single-pressure SF6 breakers. Based on a CIGRE survey of 281,090 breaker-years with responses from 82 utilities from 26 countries, source: A. Janssen, D. Makareinis and C.-E. Sölver, "International surveys on circuit-breaker reliability data for substation and system studies," *IEEE Transactions on Power Delivery*, v. 29, n. 2, April 2014, pp. 808-814

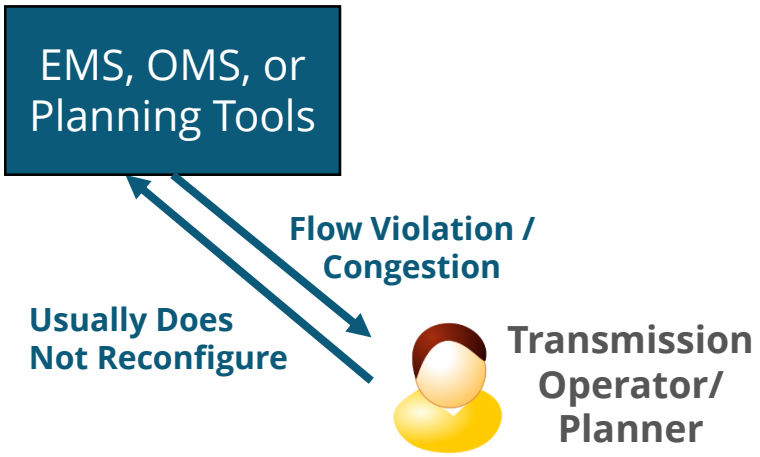
** All-in cost of maintenance overhauls for single-pressure SF6 breakers rated 72.5-362 kV.

Road closure picture from https://www.islandecho.co.uk/plea-motorists-heed-road-closed-signs/

Reconfiguration Practice

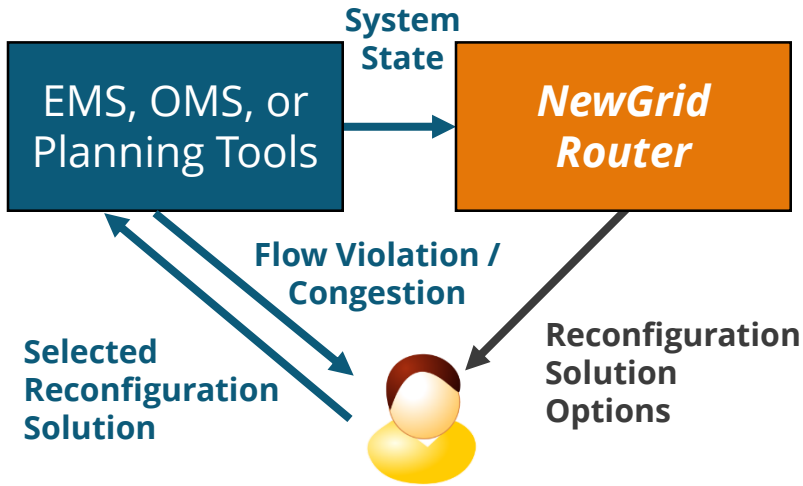
Traditional/Today

- Reconfigurations identified based on staff experience
  - Time-consuming process
  - Depends on expert operators
- Employed to a limited extent, on an ad-hoc basis, mostly for reliability applications
  - Example: PJM Switching Solutions*
  - Other RTOs have Operating Guides, usually not disclosed to market participants
- Transmission grid flexibility underutilized



With Topology Optimization

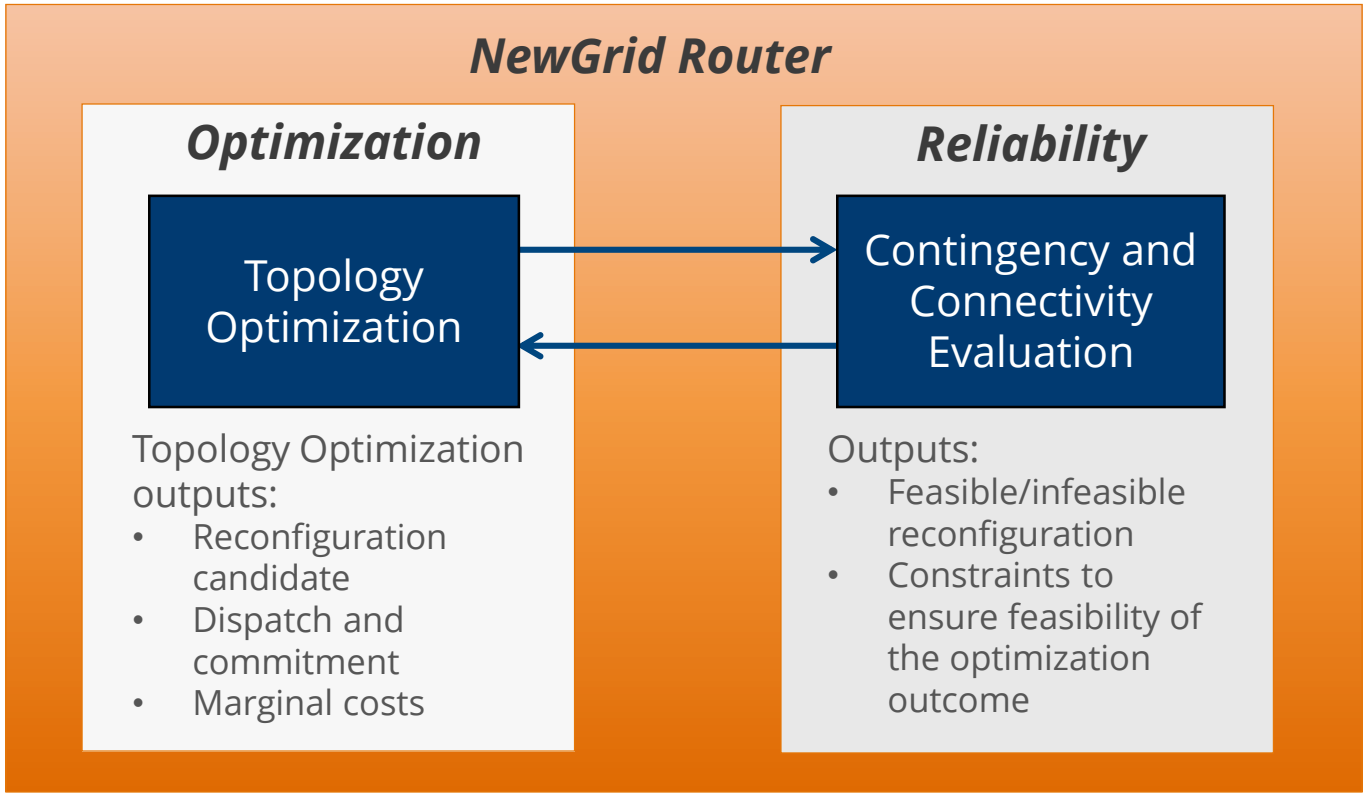
- ✓ Software finds reconfiguration solution *options*
  - Fast search time: 10 s – 2 min
  - Enables all operators to optimize the grid
- ✓ Enables broad application of reconfigurations in different processes
- ✓ Take full advantage of grid flexibility
  - Achieve better reliability and efficiency
  - ERCOT uses to support development of Constraint Mitigation Plans**



* See list at https://www.pjm.com/markets-and-operations/etools/oasis/system-information/switching-solutions.aspx.
** See reference [4] in the Appendix.

Reconfigurations Meet Reliability Criteria

The reconfigurations are feasible (e.g., do not introduce new problems) under all specified contingencies and do not radialize load beyond a user-specified value



Benefits Quantified in Case Studies

Adapting the grid configuration to best address system conditions provides reliability and economic benefits:

Improve Grid Resilience and Reliability

- **Full overload relief with outage conditions, extreme weather events** (MISO, PJM, SPP)*
- Avoid load shedding under critical contingencies (ERCOT, SPP)*
- Reduce frequency of intervals with constraint violations by 75% (SPP)*

Increase Transfer Capability

- *Large interface constraints*: **+4 to 12% capability** (Great Britain)**
- *Single-element constraints*: average flow relief over 20% (SPP, ERCOT)***

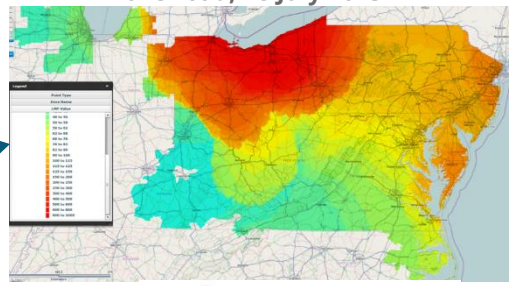
Reduce Congestion Costs

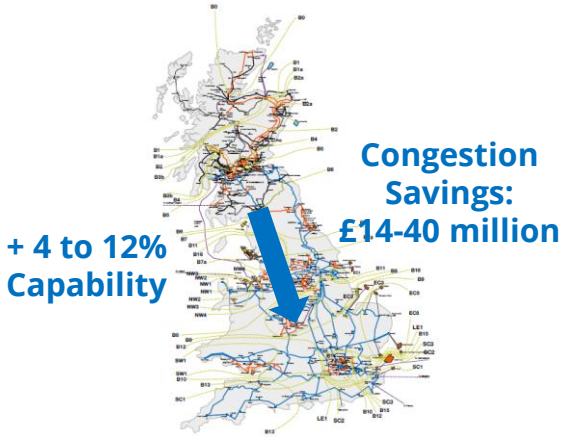
Real Time market congestion cost savings:

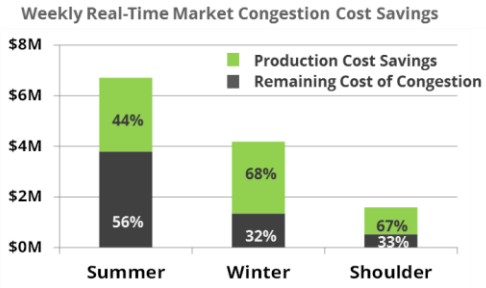
- **$100+ million/year savings** (PJM)†
- $18-44 million/year (SPP)††
- £14-40 million/year (Great Britain) **

Day Ahead savings: $145 million/year (PJM)†

PJM RT prices w/critical transformer overload, 18 July 2013







* See references [1, 3, 4, 8, 12] in the Appendix.
** See references [5, 6] in the Appendix.
*** See references [3, 4] in the Appendix.

† See reference [8] in the Appendix.
†† See reference [3] in the Appendix.

Applications

Topology optimization can be used in business processes across all time scales; the least-effort, high-value applications are in the months to days ahead

Business Process

- Long-term planning
- Seasonal contingency planning
- Outage scheduling and coordination

Low-Hanging Fruit

- Day-ahead market optimization
- Intra-day operations
- Real-time market optimization

Use Cases

- ✓ Adapt to emergency system conditions
- ✓ Increase grid resilience
- ✓ Avoid load shedding
- ✓ Enable conflicting outages
- ✓ Train new staff
- ✓ Increase transfer capability
- ✓ Relieve flow violations
- ✓ Minimize congestion costs
- ✓ Reduce wind curtailments

Deployment

Topology optimization relies on existing infrastructure to provide significant benefits under all system and ambient conditions, complementing other Grid-Enhancing Technologies (GETs), such as DLR and FACTS

Barriers to Adoption

- Incentives
  - TOs do not have incentives to operate the grid as efficiently as possible
- Market and regulatory
  - Should TO and RTO operators implement "no-cost" actions (e.g., reconfigurations) prior to implementing costly actions (e.g., redispatch or unit starts) *in all decision making processes*?
- Operations processes
  - RTOs and TO have staff constraints
  - Implementation priority of topology optimization and other GETs relative to other efforts? and FERC mandates?

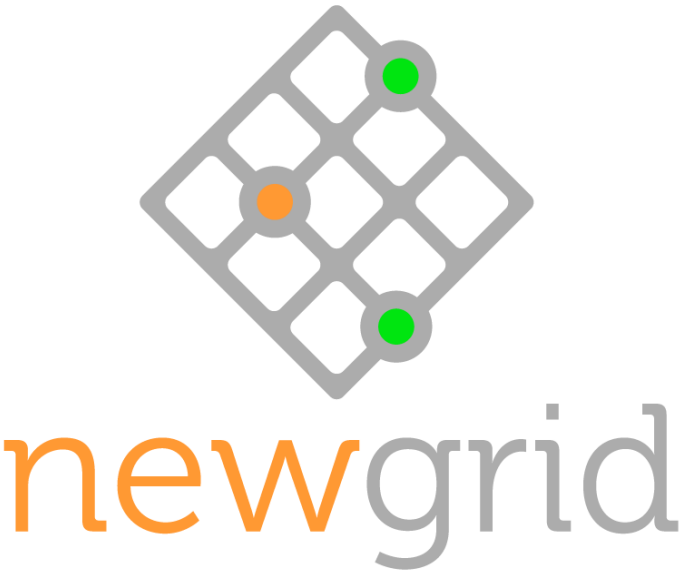
Proposed Solutions

- WATT proposal
  - Shared benefits
- FERC policy statements
  - Address market and regulatory questions as initial step to facilitate GET deployment
  - Communicate priorities
- Staged deployment, beginning with pilots
  - Simplest high-value applications first
    - Outage coordination
    - Address local reliability constraints
    - Regularly binding constraint analysis
    - Develop Op. Guides as needed
  - Later: include in market clearing

Contact

Pablo A. Ruiz
CEO and *CTO*
Pablo.Ruiz@newgridinc.com
+1.217.766.7602

75 Park Plaza, Fourth Floor
Boston, MA 02116



http://www.newgridinc.com

Appendix

References (I/II)

[1] T. B. Tsuchida and R. Gramlich, "Improving transmission operation with advanced technologies: a review of deployment experience and analysis of incentives," White Paper, June 2019. [Online] https://www.brattle.com/news-and-knowledge/publications/improving-transmission-operation-with-advanced-technologies-a-review-of-deployment-experience-and-analysis-of-incentives

[2] P. A. Ruiz and J. Caspary, Transmission Topology Optimization – A Software Solution for Improving Congestion Management," ESIG Webinar, June 2019, [Online] https://www.esig.energy/event/webinar-transmission-topology-optimization-a-software-solution-for-improving-congestion-management/

[3] P. A. Ruiz *et al*, "Transmission topology optimization: performance and benefit assessment in SPP Operations and Operations Planning," presented at *SPP Operating Reliability Working Group Meeting*, Little Rock, AR, May 2018. [Online] https://www.spp.org/Documents/57991/ORWG%20Meeting%20Materials%205-30-18.zip

[4] P. A. Ruiz and N. Steffan, "Transmission topology optimization: operations and market applications and case studies," presented at *ERCOT Demand Side Working Group Meeting*, Austin, TX, Nov 2017. [Online] http://ercot.com/content/wcm/key_documents_lists/127739/PRuiz_ERCOT_DSWG_FINAL.pdf

[5] National Grid Electricity Transmission Network Innovation Allowance Annual Summary 2016/2017, Jul 2017, page 14. [Online]https://www.nationalgrid.com/sites/default/files/documents/National%20Grid%20Electricity%20Transmission%20NIA%20Annual%20Summary%202016-17.pdf

[6] National Grid, Network Innovation Allowance Closedown Report, Transmission Network Topology Optimisation, project NIA_NGET0169, Jul 2017. [Online] http://www.smarternetworks.org/project/nia_nget0169/documents

[7] P. A. Ruiz, "Transmission topology optimization software: operations and market applications and case studies," presented at *SPP Technology Expo*, Little Rock, AR, Nov 2016. [Online] https://www.spp.org/Documents/45058/Tech Expo 11 14 16 Agenda & 20Presentations.zip

[8] P. A. Ruiz *et al*, "Transmission topology optimization: simulation of impacts in PJM day-ahead markets," at *FERC Tech Conf on Increasing Market Efficiency through Improved Software*, Docket AD10-12-007, Washington, DC, June 2016. [Online] https://www.ferc.gov/CalendarFiles/20160629114654-2%20-%20PRuiz%20FERCTechConf%2028Jun2016_FINAL_2.pdf

[9] P. A. Ruiz, E. A. Goldis, A. M. Rudkevich, M. C. Caramanis, C. R. Philbrick, and J. M. Foster, "Security-constrained transmission topology control MILP formulation using sensitivity factors," *IEEE Trans on Power Systems*, vol. 32, no. 2, Mar 2017, pp. 1597 – 1605.

Appendix 3

References (II/II)

[10] E. Goldis, P. A. Ruiz, M. C. Caramanis, X. Li, C. R. Philbrick, A. Rudkevich, "Shift factor-based SCOPF topology control MIP formulations with substation configurations," *IEEE Trans. on Power Systems*, vol. 32, no. 2, Mar 2017, pp. 1179 – 1190.

[11] J. Chang and P. A. Ruiz, "Transmission Topology Control – Applications to Outage Scheduling, Market Efficiency and Overload Relief," presented at *WIRES Summer Meeting*, Boston, MA, July 2015.

[12] P. Ruiz *et al*, "Topology Control Algorithms (TCA) – Simulations in PJM Day Ahead Market and Outage Coordination," at *FERC Tech Conf Increasing Market Efficiency through Improved Software*, Docket AD10-12-006, Washington, DC, June 2015. [Online] https://www.ferc.gov/CalendarFiles/20150623084820-W2-A-%201%20-%20RUIZ%20-%20PRuiz%20TCA%20FERC%20Tech%20Conference%202015%20FINAL.pdf

[13] E. A. Goldis, X. Li, M. C. Caramanis, A. M. Rudkevich, P. A. Ruiz, "AC-Based Topology Control Algorithms (TCA) – A PJM Historical Data Case Study," in *Proc. 48th Hawaii Int. Conf. System Science*, January 2015.

[14] P. A. Ruiz, X. Li, and B. Tsuchida, "Transmission Topology Control – Curtailment Reduction through System Reconfiguration," at *Utility Variable-Generation Integration Group Fall Technical Workshop*, San Antonio, TX, Oct 2014.

[15] P. A. Ruiz *et al*, "Transmission Topology Control for System Efficiency: Simulations on PJM Real Time Markets," presented at *2013 IEEE PES General Meeting*, Vancouver, Canada, July 2013.

[16] P. A. Ruiz, J. M. Foster, A. Rudkevich and M. C. Caramanis, "Tractable transmission topology control using sensitivity analysis," *IEEE Transactions on Power Systems*, vol. 27, no. 3, Aug 2012, pp. 1550 – 1559.

[17] P. A. Ruiz, J. M. Foster, A. Rudkevich and M. C. Caramanis, "On fast transmission topology control heuristics," in *Proc. 2011 IEEE Power and Energy Soc. Gen. Meeting*, Detroit, MI, July 2011.

[18] R. O'Neill, R. Baldick, U. Helman, M. Rothkopf, and W. Stewart, "Dispatchable transmission in RTO markets," *IEEE Transactions on Power Systems*, vol. 20, no. 1, pp. 171–179, Feb. 2005.

[19] E. B. Fisher, R. P. O'Neill, and M. C. Ferris, "Optimal transmission switching," *IEEE Transactions on Power Systems*, vol. 23, no. 3, pp. 1346–1355, Aug. 2008.

[20] K. W. Hedman, R. P. O'Neill, E. B. Fisher, and S. S. Oren, "Optimal transmission switching with contingency analysis," *IEEE Transactions on Power Systems*, vol. 23, no. 3, pp. 1577–1586, Aug. 2009.